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Effect of fenestration geometrical factors on building energy consumption and performance evaluation of a new external solar shading device in warm and humid climatic condition

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ABSTRACT

Glazed facades are being increasingly used in modern buildings in order to improve the daylight availability in the interiors, offer better external views and also add to the architectural beauty of the building. However this increased usage of glazed facades is leading to higher solar gain inside the building which is becoming a major issue in hot climatic regions. External shadings are thus used to protect the buildings from direct solar radiation which cause high solar gain as well as discomfort due to glare. The present study summarizes the effect of geometrical factors like window to wall ratio (WWR) and window positioning on the heating, cooling and lighting energy consumption of a South facing building cell in warm and humid climate. The performances of different commonly used external solar shading devices have been compared. The study also proposes the design of an external shading device which, when compared with the existing shading designs, leads to reduction in annual energy consumption of the building. The simulations were carried out using building energy simulation program EnergyPlus for the warm and humid climate of Kolkata, India. In order to validate the applicability of the new shading in other locations experiencing similar climate, the performance of the proposed shading was also evaluated for two other locations- Naples in USA and Hanoi in Vietnam. In both of these cases the new shading offered better performance than the other existing shading designs.

1. Introduction

As per statistics, buildings around the world represent 32% of the total final energy consumption (Abanda and Byers, 2016). In India, buildings account for 35% of the total final energy consumption (www.pnnl.gov). Modern buildings are often characterised by large windows of glazing materials. With the increased usage of glazed areas the heat gain in the buildings also increase leading to larger cooling load. This becomes a matter of concern in summer season especially in cooling dominant regions. Thus shadings are essential as integral parts of fenestration systems in order to reduce the cooling load of the building as well as discomfort due to glare. Shadings may be installed internally or externally, may be fixed or movable, which again may be manual or automated. Several research studies evaluate the performances of shading devices. External shadings intercept the solar radiation before reaching the building interior. Whereas, if shadings are installed internally the solar radiation incident on the glazing system get absorbed and is then re-radiated inwards causing the cooling load to increase.

The performances of indoor and outdoor shading devices have been compared by Atzeri et al. (2014) in terms of thermal and visual comfort and overall energy use. Simulations using EnergyPlus showed that use of shades improved thermal comfort, however, internal shades could cause an increase in energy demand with particular orientations and glazing types. A number of shading strategies for north and south facing office cubicles with varying floor area, window sizes and parameters were simulated by Grynning et al. (2014). The simulations were carried out using COMFEN, which is a graphical user interface tool of EnergyPlus. The study found that automatically controlled shading devices were able to reduce energy demands with proper shading strategy. It also pointed that four-pane glazing will always be beneficial compared to two and three-pane glazing systems. The impact of shading device type, properties and control on building cooling and lighting energy demand was analysed using an exterior roller shade (Tzempelikos and Athienitis, 2007). The results showed that an integrated approach for automatic control of motorized shading along with controllable electric lighting systems can bring substantial reduction in energy demand for cooling and lighting depending on the climatic conditions and orientations. The effect of vertical and horizontal louver shading devices applied to different building facades for

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different locations were evaluated using TRNSYS software (Palmero-Marrero and Oliveira, 2010). When compared to building without shading devices, the louver shadings resulted in significant energy saving and comfortable indoor thermal conditions. Ebrahimpour and Maerefat (2011) evaluated the effect of advanced glazing and overhangs on the transmitted solar radiation for residential buildings in Tehran. The annual energy use was predicted using simulation program EnergyPlus. From the results the best combination of overhangs, side fins and glazings for each window direction was determined. The effect of a series of shading devices applied to a highly glazed office building in Southern Italy was evaluated using EnergyPlus (Evola et al., 2017). Twenty-nine different types of shading devices including louvers, blinds, curtains, etc. were considered to identify the most suitable solution. The effects of solar shading strategies on thermal comfort were also evaluated for low income tropical housing in Uganda using EnergyPlus (Hashemi and Khatami, 2017). Results revealed that the shading strategies like curtains and overhangs were most effective during the hottest period of the year.

Li et al. (2016) evaluated the performance of building integrated solar thermal shading system on building energy consumption and daylight levels through simulations. The louvers were installed horizontally on the south facade and vertically on the east and west facades. The shading system reduced building energy consumption and improved interior useful daylight level. Hong et al. (2017) conducted the non linearity analysis of the shading effect on the technical-economic performance of building-integrated photovoltaic blind (BIPB). The findings can be used to define the design specifications of the BIPB before its implementation. The performance of electrochromic glazing and that of fixed external shading devices to prevent heat gains were compared by Aldawoud (2013). A typical office building was modelled using DesignBuilder software, a graphical interface for EnergyPlus, and the results showed that the electrochromic glazing provided the best performance in reducing solar heat gain. An experimental configuration of external shading device was designed and evaluated by Kim et al. (2012). Simulations carried out in energy analysis program IES_VE showed that the experimental shadings offered more efficient performance than other shading devices. Impact of louver shading properties like material, length of slats, distance between slats, etc on energy consumption, thermal comfort and daylighting were analysed by Stazi et al. (2014). Dynamic thermal simulations were carried out using EnergyPlus. An overview of the effects of shading devices on building thermal and lighting performances were analysed by Bellia et al. (2014). The performance of internal woven roller shades was also assessed in terms of energy efficiency and visual comfort using EnergyPlus by Singh et al. (2015).

Movable shading devices are more advantageous than fixed shading devices since they can be controlled effectively to block the direct solar radiation in summer and allow them in winter. However, manually operated movable shading devices depend largely on the occupants' behaviour for efficient functioning (O'Brien et al., 2013). In addition to thermal and visual preferences, manual adjustment of solar shades depends on the occupants' privacy, personal values, and even emotional conditions (Yao, 2014). This can be avoided by using automated shading devices. Firlag et al. (2015) analysed the effect of control algorithms for dynamic windows. Results showed that the use of automated shadings reduced the site energy consumption in the range of 11.6–13.0%. Additional energy consumption due to motor, sensors, etc was not much. However, the system leads to higher price, higher probability of failure and use of additional electrical energy. User acceptance is another problem in case of automatic control of shading.

Thermal and daylighting performances of several popular energy efficient window designs were simulated by Huang et al. (2014). Different types of shading devices, their properties, operations, performances and energy saving potential in different climatic regions were also evaluated in several studies (Kirimtat et al., 2016; Bellia et al., 2013; Cho et al., 2014; Nielsen et al., 2011; Al-Tamimi and Fadzil, 2011). However, proposition of new designs of shading that can effectively reduce the overall energy consumption is very rare.

The present study focuses on the effect of geometrical factors like window to wall ratio (WWR) and window positioning on the heating, cooling and lighting energy consumption of the building. In addition to that, a new external fixed shading design has been proposed and its performance has been compared with the existing commonly used external shading devices in warm and humid climate condition.

2. Methodology

2.1. Simulation tool

Study by Kirimtat et al. (2016) showed that simulation tools are significant in identifying the most suitable shading configuration for a particular building. Shading performance can be evaluated by a number of building energy simulation programs like EnergyPlus, DOE-2, IES_VE, TRNSYS, ESP-r, etc. However, the review study of simulation modelling for shading devices revealed that amongst the different tools EnergyPlus is the most widely used and the oldest one. Moreover, the tool is capable of simulating complex models accurately and in details. Thus, the present simulations have been carried out in EnergyPlus simulation software. EnergyPlus is a whole building energy simulation program which combines the best features of BLAST and DOE-2 programs (Crawley et al., 2001). It includes essential features like advanced fenestration models including controllable window blinds, heat balance-based solution of radiant and convective effects that produce surface temperatures, thermal comfort and condensation calculations, illuminance and glare calculations for reporting visual comfort and driving lighting controls, etc (EnergyPlus Engineering Reference, 2014). These features made the program suitable for the present study.

2.2. Location and climate

The present study was simulated using the weather data of Kolkata in India located at a latitude of 22.57°N and a longitude of 88.37°E (The Indian Astronomical Ephemeris, 1999). Kolkata, the capital city of the state of West Bengal, is situated in the Gangetic delta and nearer to the east coast of India.

Kolkata experiences a warm and humid climate (Energy Conservation Building Code User Guide, 2009). The long-term average of global irradiance at Kolkata is 191.4 $W\,m^{-2}$. The diffuse component accounts for 50% of the global irradiance (www.indiaenvironmentportal.org.in, 2010). Kolkata experiences an annual mean temperature of about 27 °C. The summer is hot and humid with mean temperatures about 30 °C but during dry spells the maximum temperatures often exceeds 40 °C during the months of April and May. Effective winter tends to last for only about two and a half months, with seasonal lows dipping to 12 °C between December and January (www.imdkolkata.gov.in, 2017).

Weather data of Kolkata provided by Indian Society of Heating, Refrigerating and Air-Conditioning Engineers (ISHRAE) was used to perform the simulations in the present work.

2.3. Building simulation

2.3.1. Building model description

An air conditioned building cell of dimension 5 m × 5 m × 3 m had been chosen for the present study. The South facing wall of the building had a glazed window. The detailed description of the building materials are provided in Table 1. The thermal properties of the materials were derived from ASHRAE Handbooks (1993, 2009). The thermal and optical properties of glass were derived from Pilkington Optifloat brochure (www.pilkington.com, 2017).

Table 1
Details of building materials.

Components	Layers (from outside)	Thickness (mm)	Conductivity (W/m K)	Density (kg/m^3)	Sp. Heat (J/kg K)
Roof	RCC slab	100	1.70	2240	900
	Plaster	6	0.72	1860	840
Wall	Plaster	19	0.72	1860	840
	Brick	250	0.90	1920	790
	Plaster	12	0.72	1860	840
Floor	Brick	75	0.90	1920	790
	PCC	100	1.70	2240	900
	Cement	35	0.29	1920	670
	Cork tiles	10	0.065	464.535	2010
Window	Clear glass	3	Solar Transmittance at normal incidence = 0.84 Solar Reflectance at normal incidence = 0.08 Visible Transmittance at normal incidence = 0.9 Visible Reflectance at normal incidence = 0.08		

2.3.2. Schedules, HVAC and internal gains

The parameters of HVAC, schedules and internal gains used in the simulations are described in Table 2.

An HVAC system with ideal air system had been used which kept the temperature inside the building within the heating and cooling set-points.

The internal gain from lights was set at 10.8 W/m^2, which is the maximum permissible interior lighting power density for office buildings (Energy Conservation Building Code User Guide, 2009). Continuous lighting control had been used to keep the illuminance level at 500 lux at the reference point at the centre of the building cell at a height of 0.8 m above the floor, defined by co-ordinates (2.5, 2.5, 0.8).

The building was assumed to be operational from 09:00 am to 06:00 pm on all days. Number of occupants was assumed to be 4 and the internal gain from each occupant was assumed to be 100 W.

3. Simulation results

3.1. Building performance depending on WWR

Different window to wall ratio (WWR) was applied and the annual heating, cooling and lighting energy consumptions of the building were compared. The window was assumed to be installed on the south facing wall, which had an area of 5 m × 3 m.

Case 1: The window had a dimension of 2 m × 1 m as shown in Fig. 1. The WWR in this case was 13.33%.
Case 2: The window had a dimension of 2 m × 2 m as shown in Fig. 2. The WWR in this case was 26.67%.
Case 3: In this case the building had two windows each having a dimension of 2 m × 2 m as shown in Fig. 3. The WWR in this case was 53.33%.

The total energy consumption for the three test cases for each month is shown in Fig. 4. It is evident from the figure that the total energy consumption was highest for the building with WWR of 53.33% for every month.

Fig. 5 shows the annual heating, cooling and lighting energy consumption for the three test cases. It is clear from the graph that the energy consumption increased with the window area.

For cooling dominant region maximum energy was consumed for cooling. In all the three cases cooling was required for each month of the year. The cooling energy consumption for the third case with WWR of 53.33% was the highest due to the large heat gain through the glazed

Table 2
Details of HVAC, schedules and internal gains.

Parameter	Description
Heating setpoint	20 °C
Cooling setpoint	24 °C
Lighting level	10.8 W/m^2
Lighting schedule	All days, from 09:00 am to 06:00 pm
Daylighting control	500 lux at reference point (2.5, 2.5, 0.8)
No. of occupants	4
People occupancy schedule	All days, from 09:00 am to 06:00 pm
People activity schedule	Internal gain of 100 W per person (corresponding to reading or writing approx. (EnergyPlus Input Output Reference, 2017)), All days, from 09:00 am to 06:00 pm

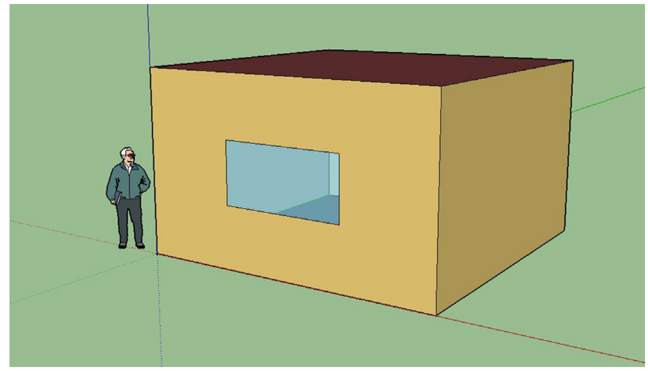

Fig. 1. Building with WWR = 13.33%.

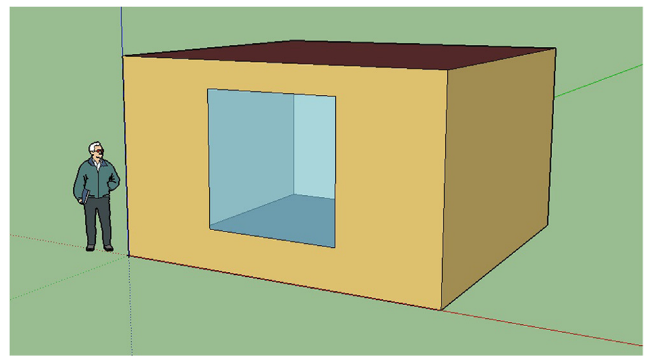

Fig. 2. Building with WWR = 26.67%.

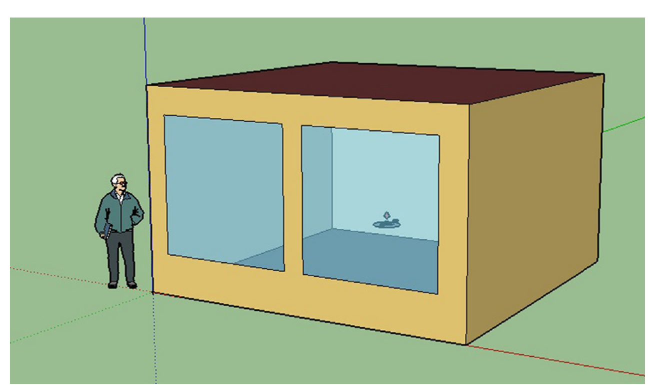

Fig. 3. Building with WWR = 53.33%.

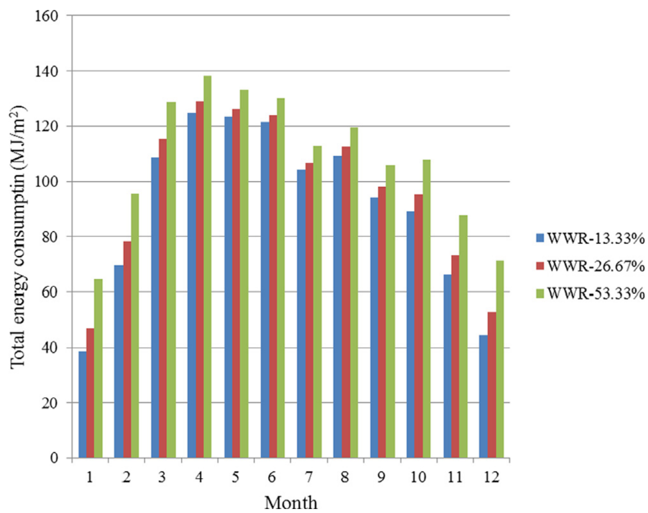

Fig. 4. Monthly energy consumptions for different WWR.

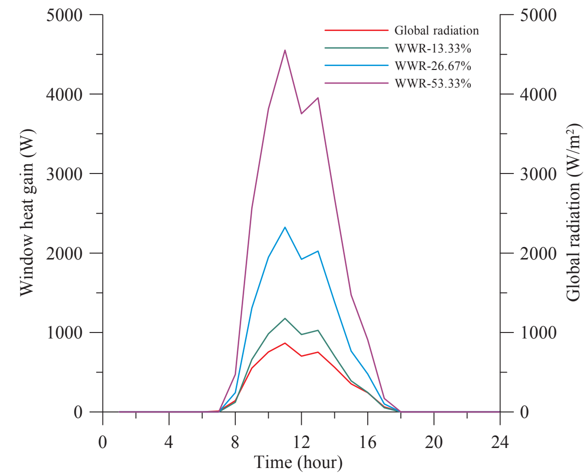

Fig. 7. Time vs Window heat gain and Global radiation on 21st Dec for different WWR.

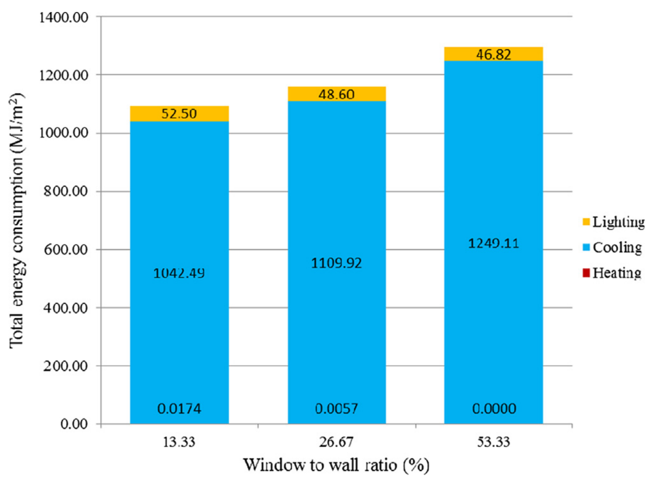

Fig. 5. Annual energy consumptions for different WWR.

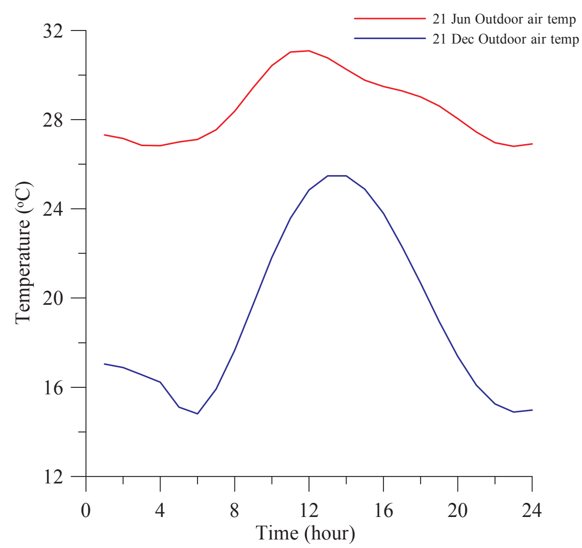

Fig. 8. Outdoor air temperature on 21st June and 21st December.

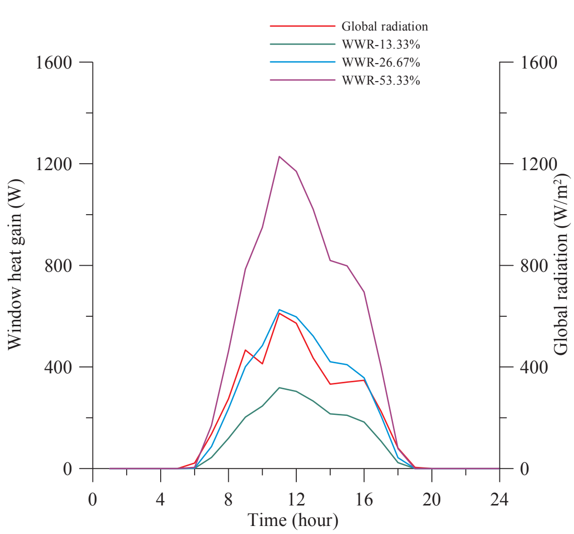

Fig. 6. Time vs Window heat gain and Global radiation on 21st Jun for different WWR.

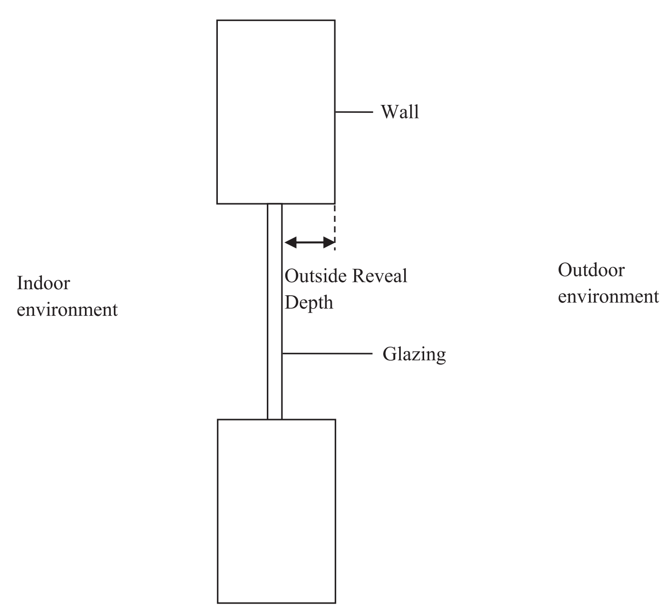

Fig. 9. Window positioning.

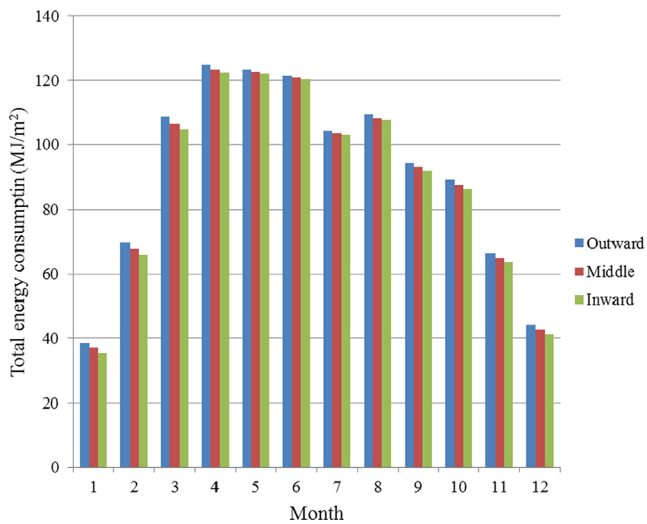

Fig. 10. Monthly energy consumptions for different window positions.

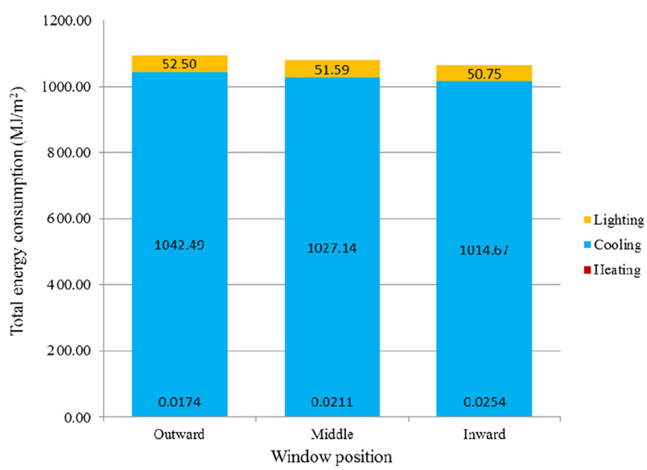

Fig. 11. Annual energy consumptions for different window positions.

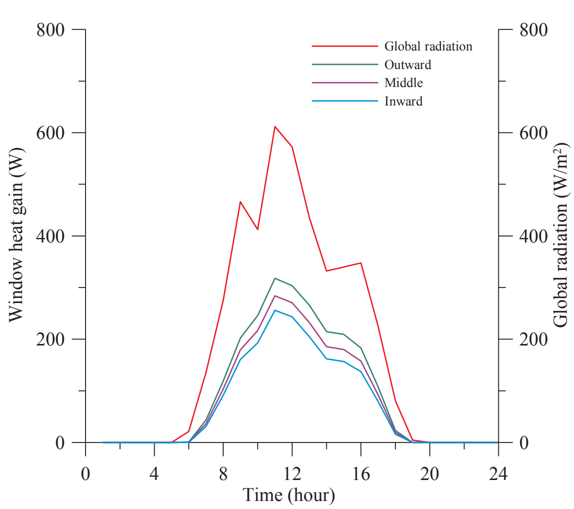

Fig. 12. Time vs Window heat gain and Global radiation on 21st Jun for different window positions.

windows. The lighting energy consumption was lowest for this case since the large fenestration area allowed sufficient daylight inside the building thus minimising the need for artificial lighting. Heating energy consumptions for all the three cases were negligible throughout the year.

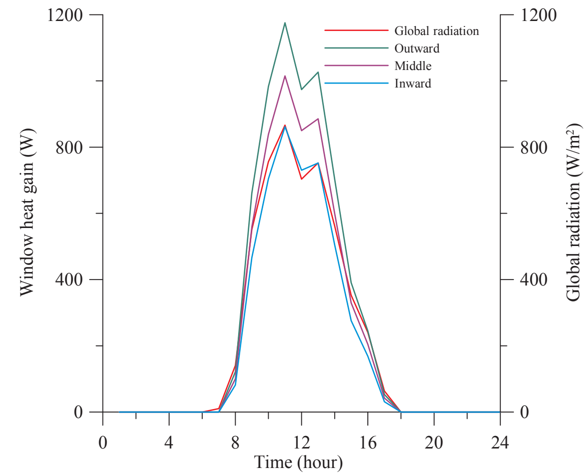

Fig. 13. Time vs Window heat gain and Global radiation on 21st Dec for different window positions.

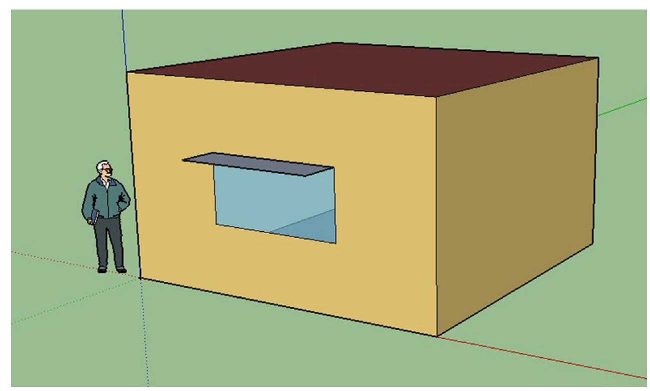

Fig. 14. Horizontal overhang.

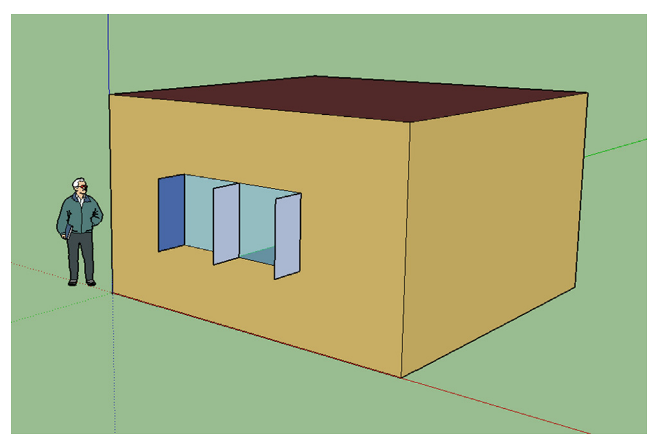

Fig. 15. Vertical fins.

Raeissi and Taheri (1998) considered the longest day of the year, 21st June, and the shortest day, 21st December to identify summer and winter solar altitudes. Figs. 6 and 7 show the magnitude of heat gain through the window for all the three cases on the longest and the shortest days i.e. 21st June and 21st December respectively. For both the days the window heat gain was highest for the building with WWR of 53.33%.

For each of the three test cases the window heat gain was higher during December than in June. This is because in winter the solar altitude angle is smaller than in summer. This allowed direct radiation

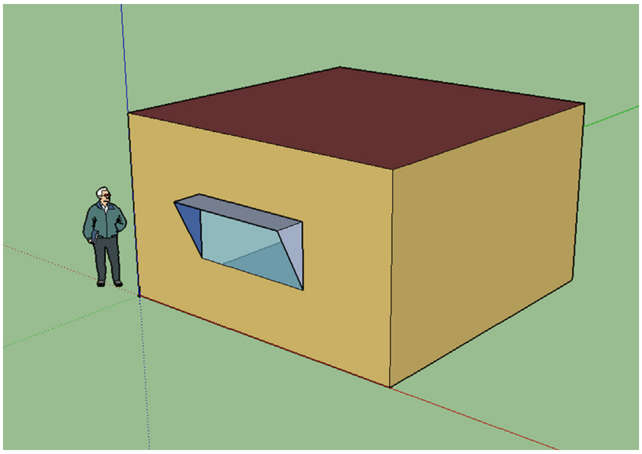

Fig. 16. Horizontal overhang with triangular fins.

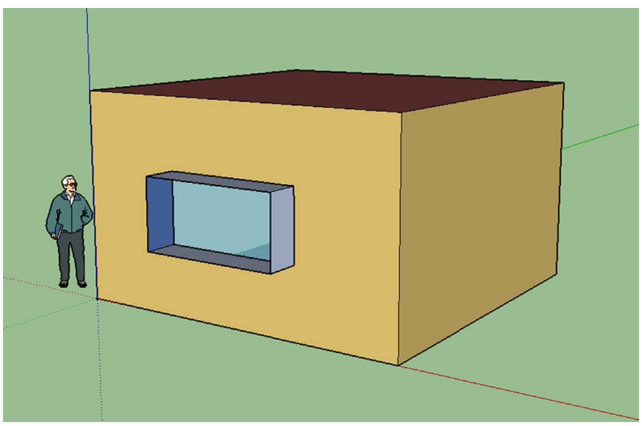

Fig. 17. Four side fins.

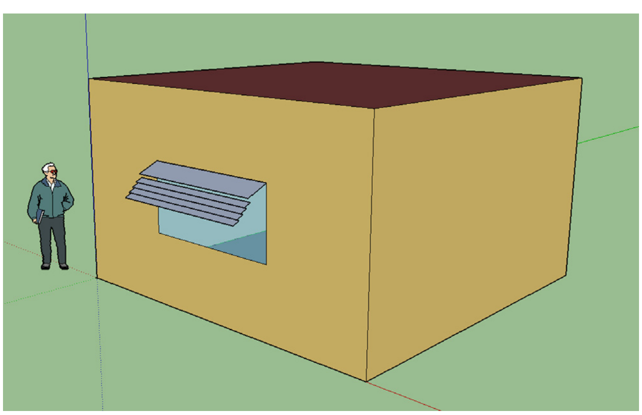

Fig. 18. New shading design.

inside the building through the window for a longer period of time. The outdoor air temperatures on 21st June and 21st December are shown in Fig. 8.

3.2. Building performance depending on window positioning

Single window of dimension 2 m × 1 m was assumed to be installed on the South facing wall of the building cell. The window was positioned at three different reveal depths, as described in Fig. 9 and the annual energy consumption for heating, cooling and lighting were compared.

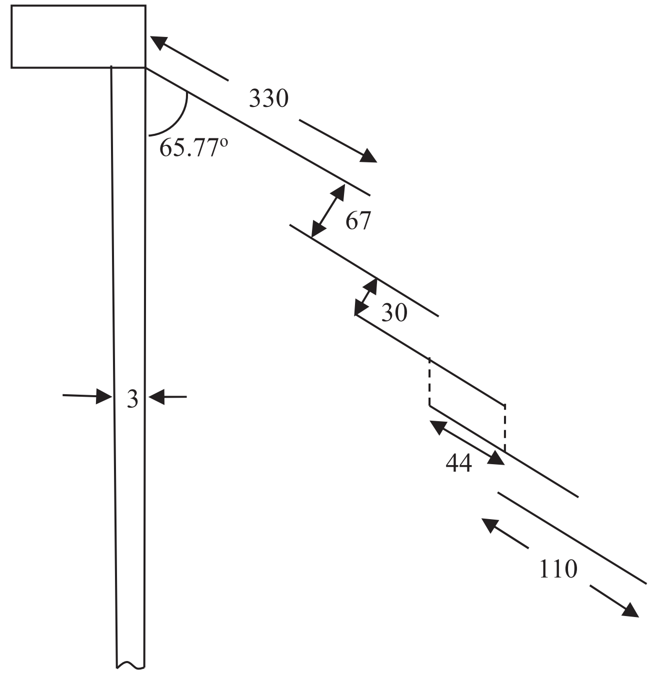

Fig. 19. Schematic diagram of the new shading design (dimensions in mm).

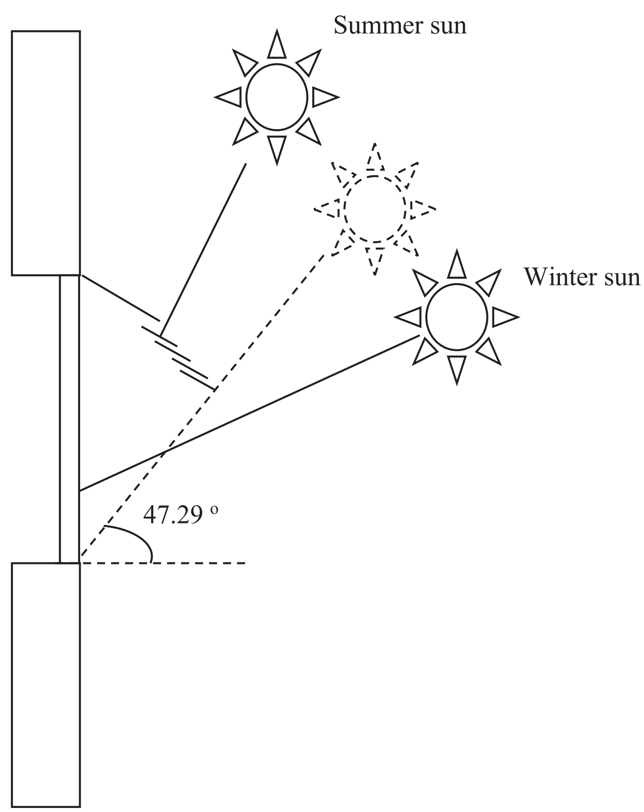

Fig. 20. Position of the Sun relative to the new shading.

Case 1: The window was positioned at an outside reveal depth of 0 m i.e. in the outward position. In this case the outer surface of the glazing and the exterior surface of the wall lied on the same plane.
Case 2: The window was positioned at the middle of the wall i.e. at an outside reveal depth of 0.139 m.
Case3: The window was positioned at an outside reveal depth of 0.278 m i.e. in the inward position.

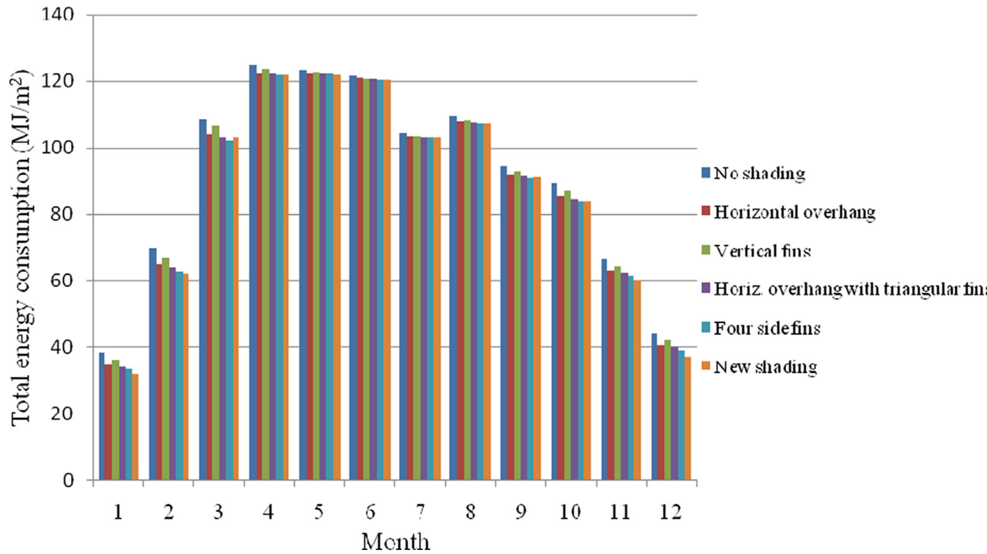

Fig. 21. Monthly energy consumptions for different shading types.

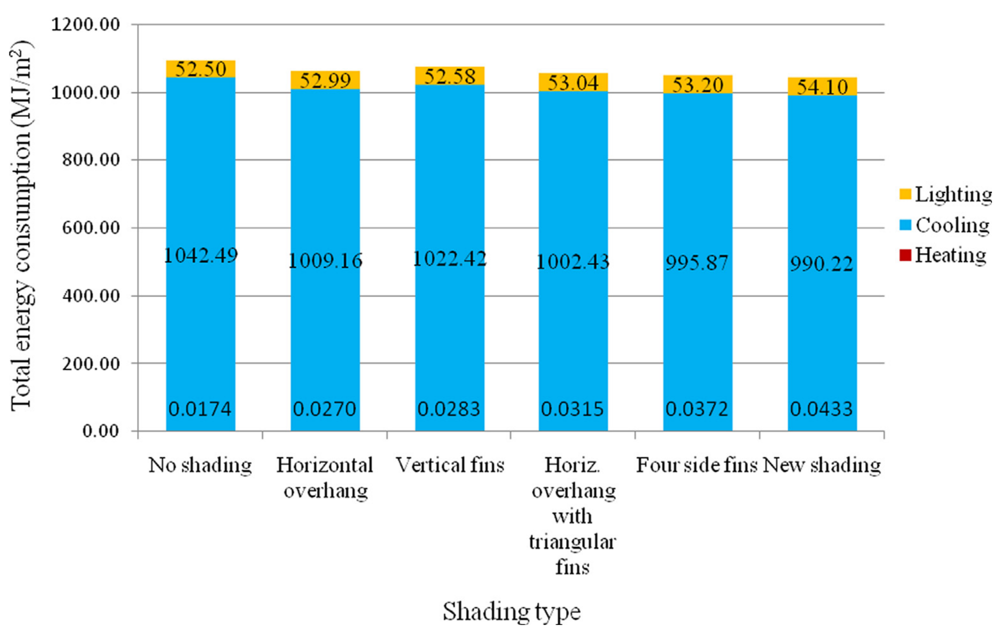

Fig. 22. Annual energy consumptions for different shading types.

The total energy consumption for the three window positions for each month is shown in Fig. 10. It is evident from the figure that the total energy consumption for each month was lowest for the window positioned inwards at a reveal depth of 0.278 m.

Fig. 11 shows the heating, cooling and lighting energy consumption for the three window positions. The graph shows that the cooling energy consumption was lowest for the window in the inward position. This is because of the presence of the reveal which acted as shadings on the four sides of the window. The lighting energy consumption was also lowest for this case because the glazing was closer to the reference point where the illuminance level was maintained at 500 lux.

Figs. 12 and 13 show the heat gain through the window for the three test cases on 21st June and 21st December, the longest and shortest days of the year. The figures show that for both the days the heat gain through the window positioned outward was the highest. The heat gain reduced as the window was moved inwards.

3.3. Building performance depending on shading type

A new design of external shading device was proposed and its performance was compared with different existing external shading devices. A window of dimension 2 m × 1 m was assumed to be installed on the South facing wall of the building cell. A test case without any shading device was used as the base case and then different external shading types were applied on the window and the energy consumptions for heating, cooling and lighting were compared.

Case 1: No shading was applied as shown in Fig. 1.
Case 2: Horizontal overhang was used as the external shading device as shown in Fig. 14. The overhang had a depth of 0.5 m.
Case 3: Vertical fins were used as the shading device. Three fins were installed each having a depth of 0.5 m as shown in Fig. 15.
Case 4: In this case horizontal overhang with a depth of 0.5 m was applied along with triangular fins on the two sides as shown in Fig. 16.
Case 5: Fins with depth of 0.5 m were applied on all the four sides of

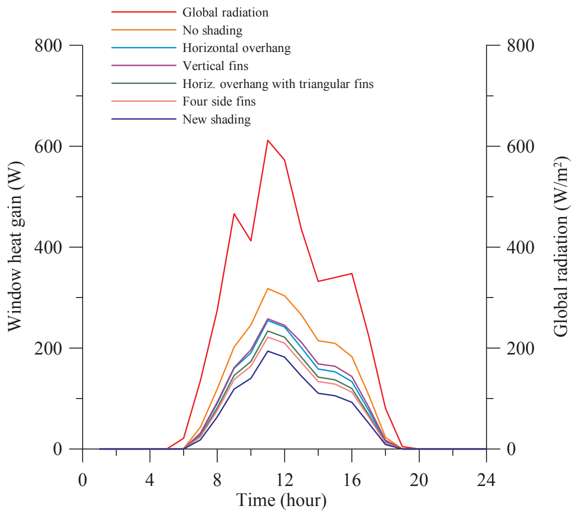

Fig. 23. Time vs Window heat gain and Global radiation on 21st Jun for different shadings.

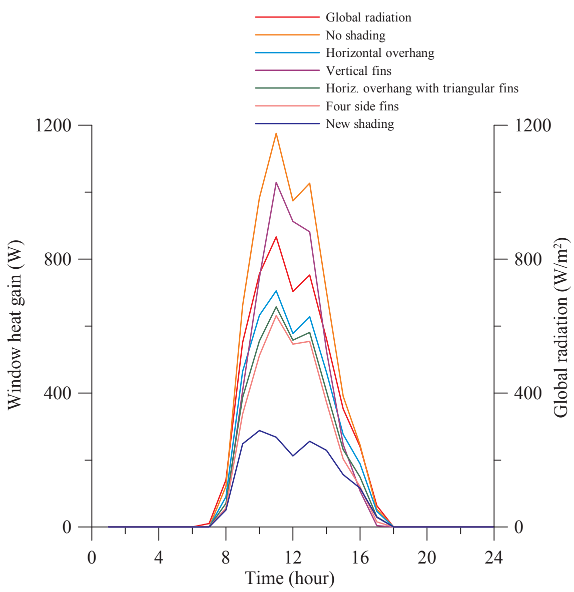

Fig. 24. Time vs Window heat gain and Global radiation on 21st Dec for different shadings.

the building as shown in Fig. 17.
Case 6: A new design of shading was applied as shown in Fig. 18. The shading device had a rectangular part resembling a horizontal overhang deflected downwards. Below this part there were four partially overlapping fins which were also deflected at similar angular deflection.

The shading dimensions and angle of deflection were adjusted to achieve the optimum values for which the energy consumption was minimum. The dimensions are shown in Fig. 19. In this case, the four fins overlapped each other partially with a gap of 30 mm between them. The gap between the rectangular part and the uppermost fin was 67 mm. Each part overlapped with its next fin for a length of 44 mm. The rectangular portion had a depth of 330 mm while each fin had a depth of 110 mm. All the parts were deflected at an angle of 24.23° with the horizontal. The lowest point of the lowermost fin was at a height of 1.585 m from the floor level. Thus, majority of the external view remained unblocked from inside.

The new shading was designed in such a way that it blocked the

Table 3
Annual energy consumptions for different test cases.

	Test cases	Heating energy (MJ/m^2)	Cooling energy (MJ/m^2)	Lighting energy (MJ/m^2)	Total energy (MJ/m^2)
Window to Wall ratio (WWR)	WWR-13.33%	0.0174	1042.49	52.50	1095.01
	WWR-26.67%	0.0057	1109.92	48.60	1158.52
	WWR-53.33%	0.0000	1249.11	46.82	1295.93
Window position	Outward	0.0174	1042.49	52.50	1095.01
	Middle	0.0211	1027.14	51.59	1078.75
	Inward	0.0254	1014.67	50.75	1065.45
Shading type	No overhang	0.0174	1042.49	52.50	1095.01
	Horizontal overhang	0.0270	1009.16	52.99	1062.17
	Vertical fins	0.0283	1022.42	52.58	1075.02
	Horiz. Overhang with triangular fins	0.0315	1002.43	53.04	1055.51
	Four side fins	0.0372	995.87	53.20	1049.11
	New shading design	0.0433	990.22	54.10	1044.37

direct radiation from the sun on summer days and allowed the radiation on winter days. Fig. 20 shows the position of the summer sun and the winter sun in relation to the new shading. The solar altitude angles were calculated for 21st June and 21st December during local solar noon using Eqs. (1) and (2) (Sukhatme, 1989):

$$\alpha = \sin^{-1}(\cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta) \tag{1}$$

$$\delta = 23.45 \times \sin\{360(284 + n)/365\} \tag{2}$$

where

α = solar altitude [∘];
δ = solar declination [∘];
ϕ = latitude of the location [∘];
n = number of days in a year (n = 1 for the first day of the year);
ω = hour angle [∘].

Using the above equations the solar altitude angle for 21st June was calculated to be 89.12° while for 21st December it was 43.98°. The new shading design blocked direct radiation above 47.29°. Thus, the shading successfully blocked the radiation from the summer sun whereas allowing the radiation during winter.

Fig. 21 shows the total energy consumption for the six test cases for each month of the year. For most of the months the energy consumption was lowest in case of the new shading resulting in minimum annual energy consumption. Fig. 22 shows the annual heating, cooling and lighting energy consumptions for the six test cases. It is evident from the graph that the lighting energy consumption for the new shading was higher than the other shading types because of the presence of fins which blocked most of the direct radiation; however, the cooling energy consumption was much lower. This resulted in minimum total energy consumption for the new shading.

Figs. 23 and 24 show the window heat gain for the different shading types on 21st June and 21st December. On both the days the heat gain through the window was minimum in case of the new shading design.

Table 3 summarizes the annual heating cooling and lighting energy consumptions of the different test cases simulated in the present study for the climate of Kolkata.

To validate the applicability of the proposed shading, the performance of the new shading device was also evaluated in two other locations – (i) Naples in USA and (ii) Hanoi in Vietnam- experiencing warm climatic condition. These simulations were carried out to find out how the proposed design would perform when applied to other places

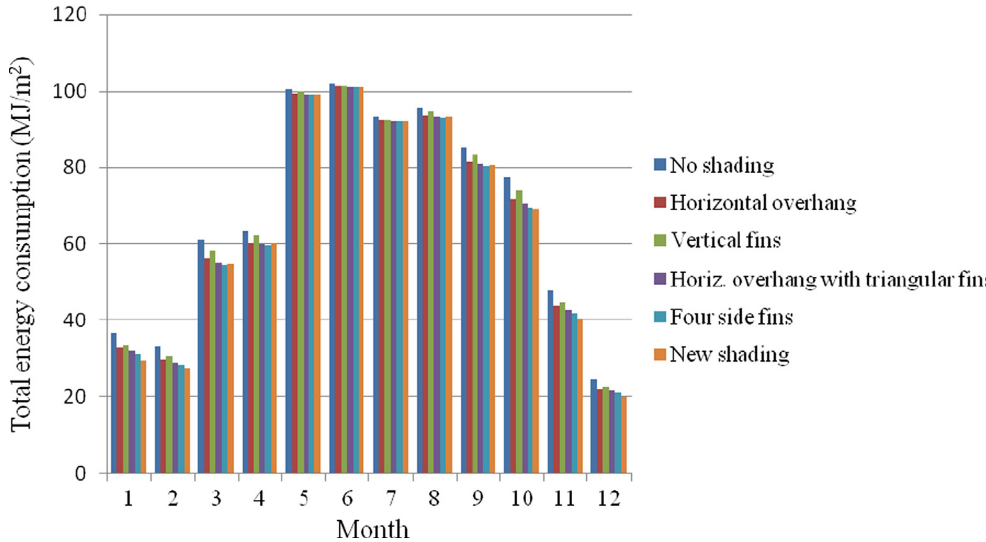

Fig. 25. Monthly energy consumptions for different shading types in Naples.

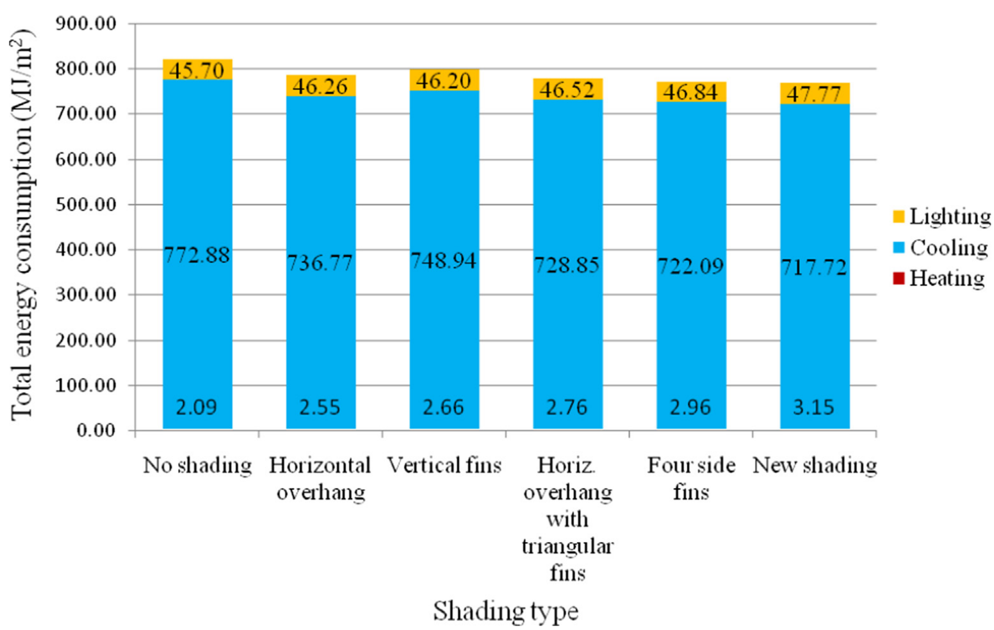

Fig. 26. Annual energy consumptions for different shading types in Naples.

with similar climate. Fig. 25 shows the monthly energy consumptions and Fig. 26 shows the annual heating, cooling and lighting energy consumptions for the city of Naples. Figs. 27 and 28 show the same for the city of Hanoi.

From the graphs it is clear that the new shading offered similar performance in these two locations as that in Kolkata. In both the cases the proposed design led to minimum cooling energy consumptions. Since these are cooling dominant regions and the cooling energy consumptions are much higher than heating and lighting energy consumptions, this resulted in lowest total energy consumptions. Table 4 summarizes the performance of the new shading compared to the other shadings in the three different locations of Kolkata, Naples and Hanoi.

From the results it was observed that the new shading performed better than the other shading types resulting in minimum annual energy consumption for all the three different locations.

4. Conclusion

The present study represents the simulation results of a number of window and shading strategies applied to a building cell for the warm and humid climate of Kolkata, India. The geometrical factors like WWR and window positioning were varied to quantify the effect of these parameters on the energy consumption of the building cell. In addition to that, a new shading device was proposed and compared to the existing commonly used external shading devices. The new shading resulted in minimum building energy consumption.

Three different values of WWR, 13.33%, 26.67% and 53.33% were applied on a South facing window of the building cell. Simulations revealed that with the increase of WWR the heating and lighting energy consumption decreased whereas the cooling energy consumption increased. This was due to the fact that as the window area increased more daylight was transmitted inside the building cell resulting in increased heating and lighting of the interior space. When the WWR was increased from 13.33% to 26.67% the heating energy consumption decreased by 67.24%, the lighting energy consumption decreased by 7.43% and the cooling energy consumption increased by 6.47%. For WWR of 53.33% the heating and lighting energy consumptions decreased by 100% and 10.82% respectively and cooling energy

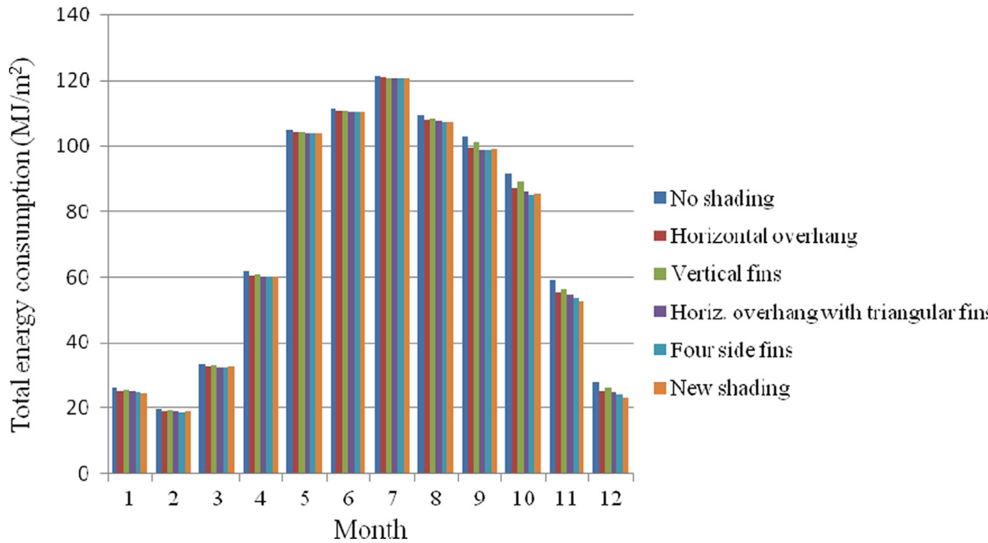

Fig. 27. Monthly energy consumptions for different shading types in Hanoi.

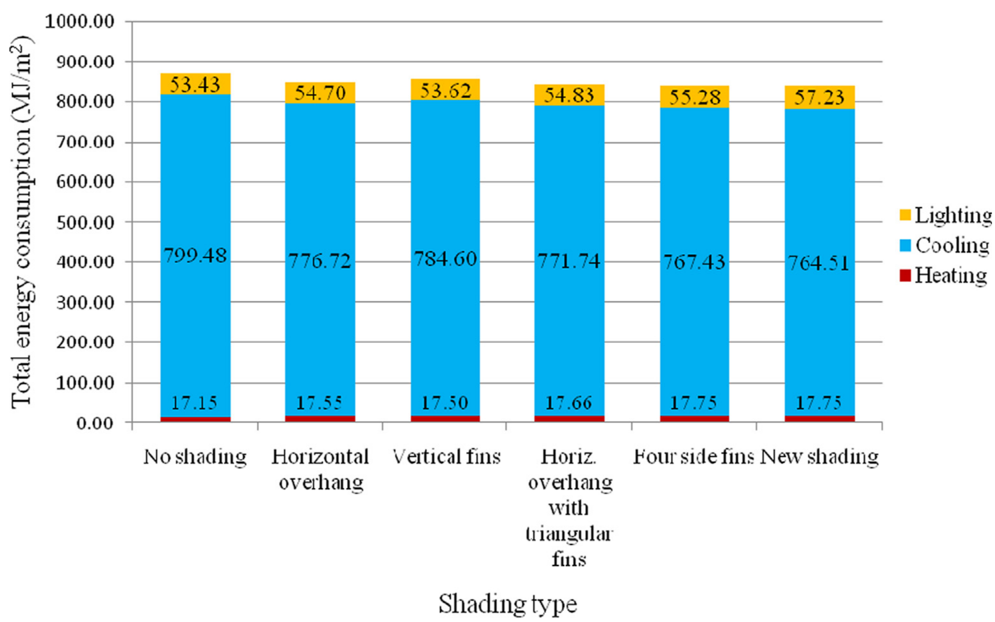

Fig. 28. Annual energy consumptions for different shading types in Hanoi.

Table 4
Performance of the different shading types in different locations.

Location	Annual energy consumption (MJ/m^2)					
	No overhang	Horiz. Overhang	Vertical fins	Horiz. Overhang with triangular fins	Four side fins	New shading design
Kolkata	1095.01	1062.17	1075.02	1055.51	1049.11	1044.37
Naples	820.67	785.58	797.81	778.12	771.89	768.63
Hanoi	870.07	848.97	855.72	844.24	840.46	839.49

consumption increased by 19.82% from the first test case of WWR 13.33%. Thus, the increase in the value of WWR resulted in the increase of total energy consumption by 5.80% and 18.35% for WWR of 26.67% and 53.33% respectively.

In the next case study the effect of positioning the window with respect to the wall was quantified. In the first test case the window was positioned outward. In the next two cases the window was moved backward in the wall by 0.139 m and 0.278 m respectively. For the second case when the window was placed in the middle position the heating energy consumption increased by 21.26%, cooling energy consumption decreased by 1.47% and lighting energy consumption decreased by 1.73% from the first test case. For the third case when the window was placed in the inward position the heating energy consumption increased by 45.98%, cooling energy consumption decreased by 2.67% and the lighting energy consumption decreased by 3.33% from the first test case. In the last two cases the outside reveal surfaces acted as shadings reducing the heat gain through the window. Thus the heating energy consumption increased and the cooling energy consumption decreased as the window was moved backwards. The lighting energy consumption decreased since the window moved closer to the reference point. This backward positioning of the window in the wall resulted in the reduction of the total energy consumption by 1.48% and 2.70% for the second and third cases respectively.

In the next case the performances of four different commonly used external shading devices and a newly proposed shading design were compared to a window with no shading device. From the simulated results it was observed that the total energy consumption reduced by 3.0% for the horizontal overhang, 1.83% for the vertical fins, 3.61% for the horizontal overhang with triangular fins, 4.19% for the four side fins and 4.62% for the new shading design compared to the window with no shading device. The new shading also blocked the direct radiation from the Sun during summer while allowing the radiation in winter. In addition it did not block the external views from inside.

To establish how the new shading would perform in other locations with similar climatic condition, simulations were carried out for two other locations- Naples in USA and Hanoi in Vietnam. In both the cases the new shading resulted in lowest cooling energy consumption leading to lowest annual energy consumption compared to other shading types. For Naples and Hanoi the annual energy consumptions decreased by 6.34% and 3.51% respectively. Thus, it can be concluded that the proposed shading design can be applied successfully to locations experiencing warm climatic conditions. However, the shading would not be suitable for places with cold climates where heating energy consumptions are significant.

Thus, it can be concluded that from the point of energy conservation, the four side fins configuration offered the lowest energy consumption amongst the existing shading designs compared in the present work. Whereas, the new shading device offered better performance than all the existing shading devices applied in warm and humid climatic condition. Though the heating and lighting energy consumptions were the highest in case of the new shading design due to the obstruction of the solar radiation, the overall energy consumption was the lowest. This was because of the fact that cooling energy consumption constitutes the major portion of the overall building energy consumption in warm climatic condition. Since the new shading was capable of reducing the cooling load to a large extent, the overall energy consumption reduced.

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